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PROBLEMS OF HEAT TRANSFER IN RAREFIED GASES

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PROBLEMS OF HEAT TRANSFER IN RAREFIED GASES

L. Ye. Kalikhman

The problems of convective heat transfer in rarefied gases are the same as in ordinary gas-dynamic conditions complicated by additional effects.

A decrease in the gas pressure leads first of all to a change in the surface conditions; a temperature jump and slippage on the wall occurs.

The processes of interaction of the flow with the surface depend essentially on the accommodation coefficient α and the coefficient of diffusion reflection σ.

The fundamental problem of convective heat transfer consists in determining the heat-transfer coefficients (the Stanton number St or the Nusselt number Nu) as functions of the parameters M, Re, Pr, $\bar{T}_{\omega}$, α, σ and the Knudsen number $Kn = M/\sqrt{Re}$.

Taking into account the effect of a temperature jump in Lees' solution for planar and axisymmetrical gas flows allows us to determine the effect of the Knudsen number on the Nusselt number at the critical point, assuming thermodynamic equilibrium. With an increase in Kn the heat-transfer intensity decreases sharply.

In this case an increase in the enthalpy factor $\bar{I}_{\omega}$ causes a re-
-ction, while a decrease in $\bar{I}_{\omega}$ causes a growth, in the heat flows. A decrease in the accommodation coefficient from $\alpha = 0.8$ to $\alpha = 0.4$ leads to an extremely sharp decrease in the heat-transfer intensity. These conclusions agree with Giedt's experiments carried out when $\bar{I}_{\omega} = 0.3$ and 0.7, when $M_{\infty} = 1.32$-5.7, and $Re_H = 30$-80.

In Giedt's experiments the Mach number has practically no effect; however, further increase of this number under low-pressure conditions should lead to freezing of the boundary layer. Consequently, the problem of heat-transfer due to recombination of atoms on the wall will be a critical one. This problem, which was sufficiently developed for a continuous medium in the works of Gulard and Rosner, has not yet been solved for rarefied gases, in view of the vagueness of the boundary conditions for an inhomogeneous gas.

We solved the problem of heat transfer of a longitudinally stream-lined flat plate by two methods: the method of linearization of equations and the method of series expansion in a small parameter inversely proportional to the free path. In the region of large Kn both solutions coincide; in the region of small Kn, as was to be expected, the second solution is unsuitable. The solution obtained is a generalization of Schaaf's solution, indicating that under equilibrium conditions StM depends not only on Kn, but on the density ratio $\rho_s/\rho_{\omega 1}$. Calculations showed that, when Kn is constant, StM depends essentially on the Mach number and to a lesser degree on the enthalpy factor I_{ω}. Large temperature jumps on the surface correspond to high Mach numbers and $\bar{I}_{\omega}$ values essentially different from unity.

... the effect of the slip velocity into account in the boundary condition for enthalpy stagnation and taking strict account of

the effect of the work of the friction force in the expression for the heat flow pose certain difficulties. Calculations taking the above factors into account allow us to conclude that at large Kn and Mach numbers these effects are extremely significant.

In this case the heat flow is not proportional to the enthalpy drop $i_e - i_\omega$. Calculations showed that the heat-transfer intensity for a longitudinally streamlined plate is sharply reduced with a decrease in α and σ.

The extension of the results relating to planar flows of rarefied gas to the case of conical flows by means of a Stepanov transformation is not feasible, due to the changes in the boundary conditions. Direct calculations of the heat flows for this case yield results coinciding with the experiments of Drake and Maslach.

(Moscow)

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